Rigorous analysis of a satellite antenna including its surrounding environment with the Dual-Grid FDTD method

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Abstract — **This paper presents a rigorous analysis of a satellite antenna mounted onto its platform using the Dual-Grid FDTD method. In the first step of the method, the isolated antenna is analyzed. The study of the surrounded antenna is carried out in the second step of the DG-FDTD method. The results obtained in this realistic test case show the significant influence of the environment over the antenna.**

Key words — ***Multi-scale simulation; surrounded antenna; DG-FDTD; FDTD method.***

I. INTRODUCTION

The quality of services offered by a satellite strongly depends on the performances of its antennas which have to respect stringently the expected specifications. This aspect is even trickier since the characteristics of the antenna may change with the environment of integration. Indeed, the platform sometimes contributes significantly to the radiation and must therefore be included in the antenna analysis. As a consequence, the electromagnetic computation has an essential role to play in the antenna design process to avoid the manufacture of wasteful prototypes [1,2].

The rigorous analysis of an antenna mounted on a satellite requires to simulate the electromagnetic behavior of a very large structure taking into account very small details. These multi-scale problems are by nature very consuming in computing resources. Moreover, the antenna has usually to be analyzed over a wide frequency band to fit new applications with either increased bandwidth or frequency reconfigurability.

Rigorous time domain method such as Finite Difference Time Domain (FDTD) or Transmission Line Matrix (TLM) have been proven to be well suited to analyze complex electromagnetic structures over a wide frequency range with a single simulation run [3,4]. However, the computation burden can be prohibitive for such large integration problem. In fact, the antenna often requires a fine description to deal with near-field parameters whereas its environment does not need such a meshing. As a result, the uniform spatial meshing of the overall FDTD volume leads to oversampled areas inside the computational volume that finally increases the simulation time.

Several works have been reported to overcome this limitation by coupling those full-wave techniques with asymptotic approaches such as Physical Optics (PO) or Physical Theory of Diffraction (PTD) [5,6]. The approach faces two main difficulties when dealing with the nearby environments. On one hand, the hybrid method cannot take into account accurately the strong interactions between the antenna and its environment. On the other hand, the computational domain of the full wave domain cannot be enlarged sufficiently because of the required computing resources.

Another approach consists in using time domain full wave techniques with different cells size over the computational domain [7] to avoid the oversampling phenomena and thus reduce the computer resources. This approach is known in the literature as "subgridding". It allows simulating accurately antennas with very complex nearby environment but often generates instabilities. The Dual-Grid Finite Difference in Time Domain (DG-FDTD) method [8] masters this limitation by breaking down sequentially the problem. Indeed, the DG-FDTD successively combines two or more FDTD simulations with different resolutions to compute rigorously and efficiently multi-scale problems. This method has demonstrated its ability to compute multi-scale problems with dimensions up to several wavelengths at the highest frequency [9].

In this paper, DG-FDTD is faced to the analysis of a choke horn antenna placed onto a large satellite platform which includes a nearby antenna. The first part of this paper is dedicated to the description of the structure. Then we present the DG-FDTD principle. Afterwards, the results of the two DG-FDTD steps are discussed.

II. TEST CASE DESCRIPTION

A. The horn antenna

In this paper we consider an X band telemetry antenna mounted onto the upper face of satellite platform. The antenna has been designed to radiate an iso-flow pattern and a circularly polarized field. The horn is made up of an open-ended circular waveguide loaded by four concentric rings as described in the Fig. 1. The parameters of the rings (diameters, depths and widths) and the diameter of the waveguide have been optimized at the operating frequency of 8.3 GHz to keep an axial ratio below 6 dB and to have a gain between 2 dB and 10 dB for θ between -60° and +60°.

At the highest frequency (12 GHz), the size of the radiating part of the structure is about 12λmin × 12λmin × 1,3λmin. It is worth noting the isolated antenna itself can be considered as an electrically large structure.

B. Environment of integration

We consider a realistic integration environment where the studied antenna is surrounded by another one of 1 m x 0.2 m x 0.35 m as described in the Fig. 2. This antenna is made up of rectangular plate of metal. The two antennas are arranged on an infinite ground plane modeling the body of the satellite platform. As mentioned above, we have to carry out the analysis of this structure up to 12 GHz. At this frequency, the simulation domain is very large electrically and measures $60\lambda_{min} \times 42\lambda_{min} \times 15\lambda_{min}$.

III. DG-FDTD PRINCIPLE

Consider the open problem presented in Fig. 3. As we can see in this figure, the antenna is mounted on a large structure that represents its environment. Given the proximity of the environment, we must simulate the overall problem to take into account the coupling effects that may generate disturbances in the radiation patterns. As shown in Fig. 4, using the DG-FDTD approach, the simulation is divided into two different FDTD simulations. We first define a finely discretized FDTD volume that only includes the antenna above an infinite ground plane. This FDTD volume is terminated by Perfectly Matched Layers (PML) Absorbing Boundary Conditions (ABC) in order to simulate an infinite problem. This simulation goes from t_0 to $T_{obsfine}$, where $T_{obsfine}$ is chosen so that all the electromagnetic energy has been radiated outside the FDTD volume. Therefore, we get the 'primary' radiation of the antenna, that is to say its radiation when no disturbing environment is involved. Such a radiation is calculated with a good accuracy thanks to the fine meshing.

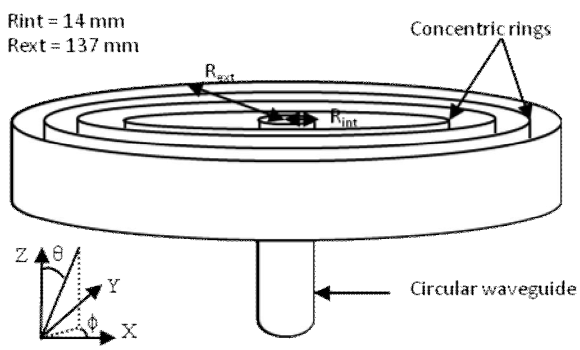

Fig. 1: the corrugated horn antenna

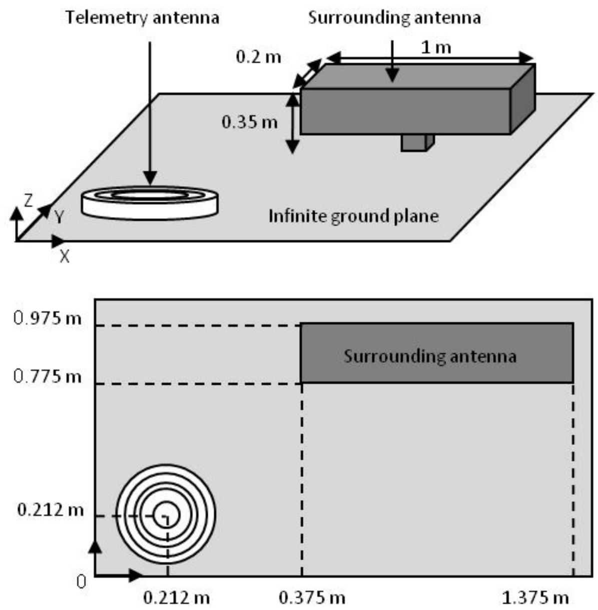

Fig. 2: Nearby environment of the antenna

The second step consists in using this primary radiation as the excitation of a coarser FDTD simulation that represents both the antenna and its environment. This coarse FDTD simulation also starts at t_0, but ends at $T_{obscoarse}$ which is larger than $T_{obsfine}$, because of the size of the surrounded problem. Note that it is essential to include a coarse description of the antenna in the coarse FDTD volume to deal with second-order scattering phenomena. Indeed, it guarantees that all coupling effects between the antenna and its environment are taken into account. Finally, the antenna generator is switched off during the second FDTD simulation since the incident power is already present in the primary radiation that is used as the excitation of the coarse FDTD volume.

To sum up, the DG-FDTD enables the characteristics of the antenna without its environment to be determined, but also makes possible the computation of the surrounded

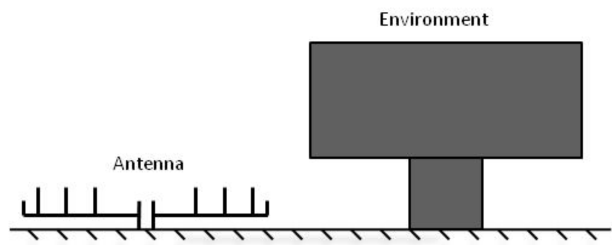

Fig. 3: Electromagnetic problem : the surrounded antenna

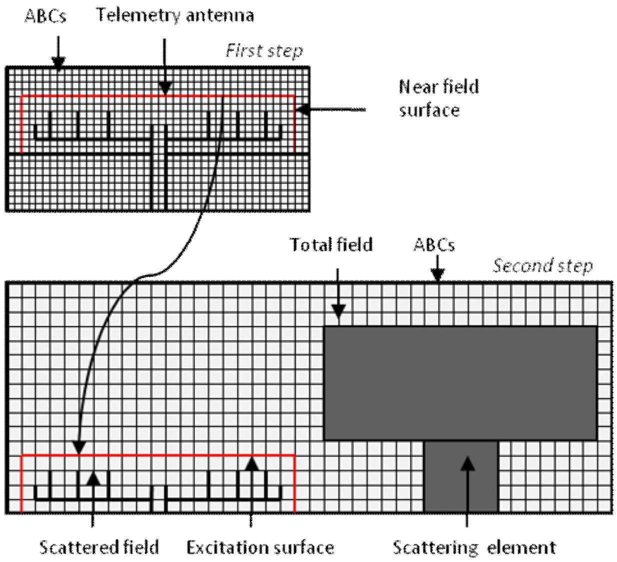

Fig. 4 : DG-FDTD principle.

performance of the antenna in a fast way. As a result, the DG-FDTD turns out to be well adapted to problems that imply a lot of simulations where the environment is changed. Indeed, once the antenna has been characterized with the fine FDTD, it can be quickly simulated in various configurations thanks to the coarse FDTD. Furthermore, since there is no field interpolation or integration along the computation time, the DG-FDTD remains stable.

IV. Numerical results

A. The isolated antenna

In the first step of the DG-FDTD approach we analyze the antenna above a ground plane in order to get the 'primary' radiation of the antenna. To ensure a good meshing of the curve surfaces in the rectangular grid, the structure has been modeled using a very fine λ_{min} /50 mesh. Moreover, in this paper the antenna is only excited along the x axis. The circular polarisation parameters could be obtained after a post-processing step.

Fig. 5 shows the directivity of the total electric field in the $\Phi = 45°$ plane at the operating frequency of 8.3 GHz. We can observe the far-field pattern is perfectly symmetric which is consistent with the symmetry of revolution of the structure.

Fig. 6 shows the evolution of the directivity of the total electric field in the $\Phi = 45°$ plane versus theta at three frequencies. Results indicate that the field pattern change significantly over the frequency range of analysis.

B. The surrounded antenna

The second step of the DG-FDTD does not need a fine resolution to be described accurately. Consequently, we use a λ_{min}/10 mesh. Moreover, compared to a fine FDTD simulation, a coarse description of the structure allows saving computing resources.

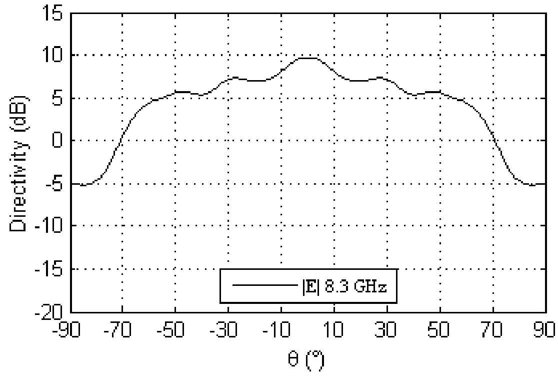

Fig. 6: Directivity of the E_Φ component in the Φ=90° plane

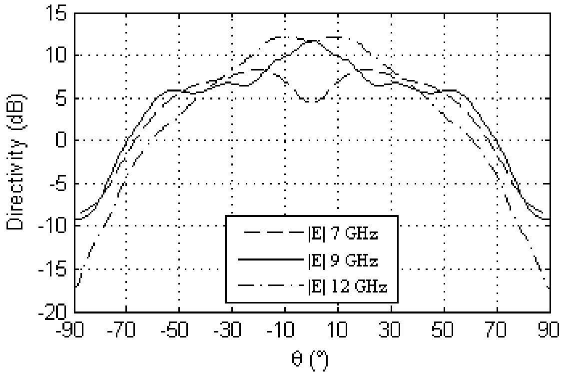

Fig. 5: Directivity of the E_Φ component in the Φ=90° plane over the frequency band of analysis

The directivity patterns of the antenna in the $\Phi = 45°$ plane at the operating frequency for the surrounded antenna and the isolated antenna are presented in Fig. 7. It appears clearly that the electromagnetic environment alters the radiation pattern for θ between +65° and +90°. More precisely, we can observe a directivity drop which is characteristic of a shadowing effect. Furthermore, the oscillations that can be seen on the surrounded directivity pattern are the consequence of the interferences caused by the introduction of the scattering element. Thus, these results show the necessity to simulate the antenna in its integration environment. Moreover, we can observe in Fig. 8 and Fig. 9 the directivity pattern is altered all over the frequency band of analysis.

Table I sums up results in terms of computational times for the two steps of the DG-FDTD obtained by means of a quad core Intel Xeon machine with 48 Gb RAM. By way of comparison, the computational time needed to perform the analysis of the surrounded antenna with a standard FDTD using the fine resolution (λ_{min}/50) is indicated in the last column. This computational time has been estimated with a dedicated tool.

V. Conclusion

A computation of a satellite antenna mounted onto the upper face of a satellite platform using Dual-Grid FDTD is performed in this paper. The DG-FDTD demonstrates its ability to simulate a multi-scale problem with strong interactions between the antenna and its environment. Moreover, the test case considered here allowed us to demonstrate the relevance of the DG-FDTD on a very large computational domain.

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TABLE I. COMPUTATIONAL TIME FOR THE DG-FDTD STEPS

	DG-FDTD first step	***DG-FDTD second step***	***Fine FDTD (estimation)***
Computational time	61 h 30 min	30 h 16 min	3 years and 2 months

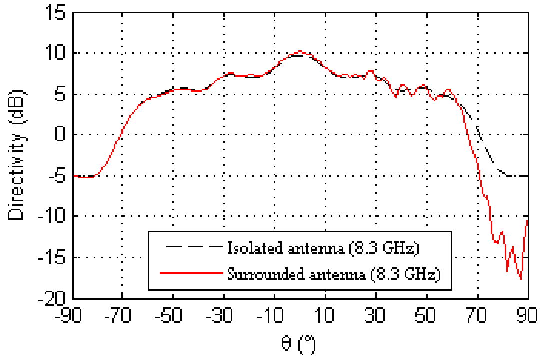

Fig. 7: Comparison at 8.3 GHz of the directivity in the Φ=45° plane between the surrounded and the isolated antenna

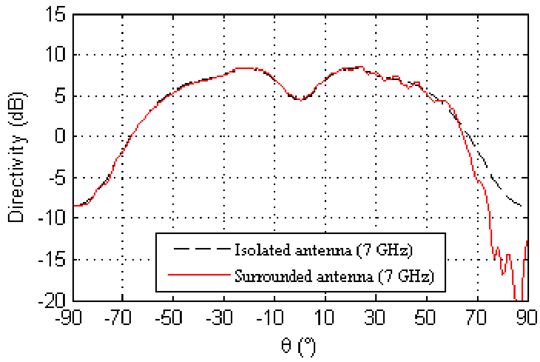

Fig. 8: Comparison at 7 GHz of the directivity in the Φ=45° plane between the surrounded and the isolated antenna

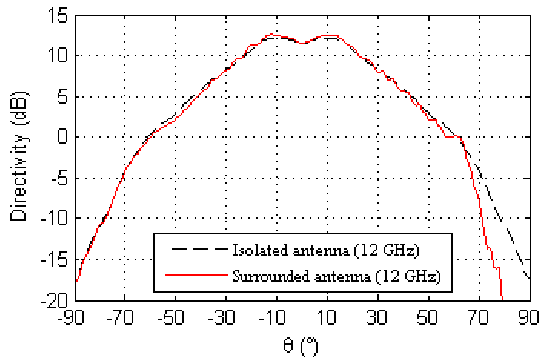

Fig. 9: Comparison at 12 GHz of the directivity in the Φ=45° plane between the surrounded and the isolated antenna